

Joint Position Sense in the Normal and Pathologic Knee Joint

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Summary: Joint position sense has been suggested to be an important factor in the etiology of degenerative joint disease. It is also believed to be important in the rehabilitative process after reconstructive surgery of the knee. Despite this awareness, in many areas of orthopaedic surgery little effort has been devoted to study of this crucial topic. Therefore, we conducted several studies of knee joint position sense by measuring the ability of healthy subjects to reproduce an angle and detect the threshold of motion. Our goal was to evaluate the effects of the following factors: aging; degenerative joint disease; total knee replacement, i.e., both absence of the anterior cruciate ligament (ACL) and sensory loss due to the absence of capsular structures; fatigue; athletic training; disruption and reconstruction of the ACL; and the role of ligament mechanoreceptors. Our results show that normal individuals can actively reproduce an angle with their knee to an average error of 2.5°. Furthermore, normal subjects require passive movement of ~2.5°-4° to detect a change in position at the speeds used in this study (~0.5°/s). Muscular training improves the ability to detect motion. On the other hand, muscular training and fatigue appear to decrease the ability to reproduce an angle. Changes in the knee and its associated structures caused by damage (ACL disruption, arthritis, total knee replacement) as well as aging uniformly cause deterioration of joint position sense. Total knee replacement and arthritic change cause the greatest deterioration. Reconstruction of ligamentous structures and/or rehabilitation appears to restore joint position sense to a near normal level. **Key Words:** Knee joint position sense—Degenerative joint disease—Reconstructive knee surgery—Healthy subjects.

Orthopedists have long recognized that sensory innervation of the knee is important in controlling motion and protecting the knee from movement beyond its anatomic limit. As early as 1944, Abbott et al. (1) noted:

The ligaments have a rich sensory innervation which allows them to act as the first link in the "kinetic chain," as described by Payr and epitomized in "Hilton's Law." At the other end of the chain is the

strong group of muscles which move the knee. Impulses arising in the ligaments are transmitted through the central nervous system back to the "effector" muscles, thus maintaining the normal, smooth, coordinated motion of the joint. Abnormally strong impulses, such as are initiated when the ligament is forcibly overstretched, result in contraction of the allied muscle groups, thereby protecting the ligament and preventing further injury and subluxation of the knee.

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The importance of joint position sense has been repeatedly acknowledged in the orthopaedic literature. Because many investigations relating to this subject have involved the study of total knee arthro-

plasty (TKA) patients, it is vital to understand two things about this procedure: first, it entails removal of the anterior cruciate ligament (ACL) and meniscus and alteration of the capsular ligaments; second, these changes may have an effect on position sense response.

Kennedy et al. (38) hypothesized that a failure of the mechanoreceptor feedback was a factor in progressive knee instability. Andriacchi et al. (3) noted differences in stair-climbing ability in patients with different total knee prosthesis designs and considered loss of joint position sense as a possible explanation. In a study of proximal tibial osteotomy patients, Prodomos et al. (46) reported that clinical failures occurred in patients who continued to walk with a high adduction moment at the knee postoperatively. They proposed that diminished joint position sense led to this compensatory gait pattern. Some of the gait abnormalities noted by Stauffer et al. (53) in patients with tricompartmental gonarthrosis, or degenerative disease of the knee, were believed to be a compensatory mechanism for loss of kinesthetic feedback from diseased knees. Knees with such changes have ACLs that are usually lax or absent; in addition, these ligaments, as well as the capsular structures, have abnormal length/tension relations (47).

Noyes et al. (45) attempted to maintain the vascular supply to intraarticular patellar tendon grafts to limit the necrosis and revascularization process as well as to maintain neural input from the graft, presumably to reestablish the ability to discern joint position. Insall et al. (31) believed that the intraarticular iliotibial bone block transfer served a function in signaling joint position sense. Failed ACL reconstructions have also been attributed to loss of joint position sense. duToit (18) reported that failure of Hey Groves' free and pedicled fascial substitutions for reconstruction of the anterior cruciate ACL and tibial collateral ligaments was due not only to late stretching, but also to "a loss of proprioceptive nerve endings with loss of the feedback mechanism and reflex postural tone of muscles."

The neuroanatomy of the knee has been a concern for many years. An anterior and a posterior group of nerves consistently supply the knee, but the most prominent is the posterior articular nerve arising from the posterior tibial nerve in the popliteal fossa (38). The neural pathway is well established for conduction of these afferent impulses to the cerebral cortex, resulting in cortical consciousness and a high degree of spatial orientation. The

response of articular receptors to passive motion and generation of reflex contraction of muscles around the knee joint has been confirmed by numerous investigators (2,11,13,21,22,24,34). Johansson et al. (34) recently showed that 40-N loads on cat ACL evoked clear hamstring and gastrocnemius-soleus responses, supporting the role of the ACL in controlling joint stability.

Although numerous studies have demonstrated mechanoreceptors in various anatomic structures of the knee (2,11,13,21,22), Schultz et al. (47) recently demonstrated these mechanoreceptors in the ACL for the first time suggesting "a role in proprioceptive reflex arcs." Schutte et al. (48) identified three distinct mechanoreceptors in the ACL near the tibial attachment and attributed these receptors to appreciation of speed, acceleration, and position.

Despite interest and speculation for many years regarding the importance of knee joint position sense, very little has been done in the way of direct measurement. Before the studies we describe, few investigators considered joint position sense in humans. In 1954, Browne et al. (12) reported diminished sensation to passive motion after anesthesia of the great toe. Cross and McCloskey (16) reported no change in position sense after metacarpophalangeal replacement. Grigg et al. (24) reported that patients undergoing total hip replacement showed increases in the threshold of motion detection of 1.7–415% for the operated side as compared with the "normal" side, but concluded that joint position sense was not dependent on the presence of the capsule and joint surface. Clark et al. (14) reported that intraarticular anesthesia of the knee had no effect on position sense, suggesting that capsular receptors are not next to the synovial lining and are therefore not affected by the diffusion of lidocaine. Kokmen et al. (40) evaluated the sensitivity of perception of motion in the metacarpophalangeal and metatarsophalangeal joints in young and elderly normal subjects. Although older subjects detected motion less well at low frequencies, the investigators concluded that no major decrease in joint motion sensation occurred.

Several unanswered questions remained after review of the available data on knee joint position sense. Does this ability diminish after TKA and does diminished joint position sense promote prosthesis loosening? Does joint position sense deteriorate with age? Does loss of joint position sense explain the inability to achieve normal function after TKA or ACL disruption? Does reconstruction of

the ACL restore joint position sense to normal? Does rehabilitation of knee joint musculature affect joint position sense and kinesthetic ability? To address these questions, we designed studies to measure these quantities (4-9,49-51). We chose a protocol (14,24,28) using the ability to reproduce a knee angle and the ability to detect the onset of slow, passive motion similar to the methods documented on human subjects by Grigg et al. (24), Clark et al. (14), and Horch et al. (28).

METHODS

An apparatus was designed to position subjects consistently and eliminate all external clues to limb motion except those emanating from the knee and surrounding tissue (Fig. 1). Subjects were seated, reclining to 60° to encourage relaxation and with legs hanging freely over the side of the seat at a distance 4-6 cm proximal to the popliteal fossa. Custom-made Jobst air splints were fitted above and below the knee joint and inflated to 20 mm Hg to neutralize cutaneous sensation. The inflated thigh cuff was then immobilized in a flexible orthoplast splint using velcro straps to ensure the same starting position for each repetition. A wire was attached to the tip of the leg air splint and used to effect passive movement of the extremity.

Reproduction of Passive Positioning

Subjects were blindfolded to remove visual input. Starting with the subject's legs in a free-hanging position of 90°, the examiner moved one leg by pulling the attached wire at a slow steady rate of ~10°/s. The leg was pulled along the natural line of exten-

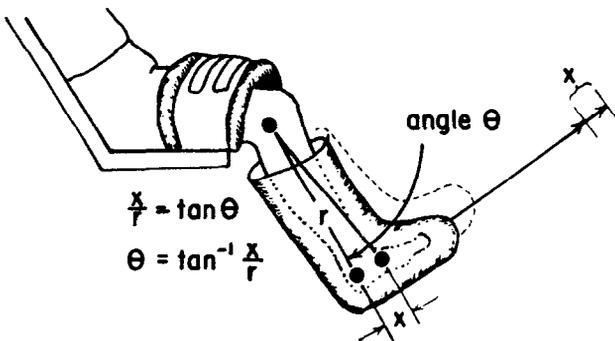


FIG. 1. Test apparatus.

sion of the leg to a random angle of from 5° to 25° of extension from the starting position. Motion was totally passive with no assistance from the subject. The extremity was held in this position for 2-4 s, and the subject was asked to concentrate on the present position in which the leg had been placed. The knee was returned to the starting angle, and the subject was asked to return the leg to the previous position.

Because the leg was moved along a line approximately tangential to the arc of motion of the leg, the linear displacement in millimeters can be converted to angular displacement accurately. The length from the medial joint line of the knee through the medial malleolus and to the heel was measured in each subject and used as the radius of curvature of the arc. The angular displacement was thus approximated.

The test was repeated 10 times (five times on each leg), and a mean value was calculated. The accuracy of position reproduction was interpreted as being inversely proportional to the magnitude of this value, which was expressed in degrees.

Threshold of Passive Motion Detection

Both leg air splints were suspended by wire attached to pulleys driven by a slow speed motor with a long shaft extending from it. The position of the pulleys on the shaft could be adjusted to pull the legs along their natural arc of extension. A starting position of 60° of flexion as measured by a goniometer was used so that the pull of gravity was already applied to the wire except in the ACL disruption and reconstruction groups which had a starting position of 40°. This served to minimize any cues to onset of motion. The motor was started with neither pulley engaged, and the subject was given a control box with an on-off switch. Subjects were informed that one of their legs would be slowly raised at a random time from 5 to 30 s after the motor was started. This served to eliminate auditory cues. The shaft slowly moved at a precalibrated rate that produced an angular deflection of 0.5°/s once the pulley was engaged. When subjects detected a movement and pressed the button, they were asked which leg had moved as a further control of validity of response. The linear movement of the wire was measured in millimeters and converted to angular deflection as described above. Ten repetitions were performed on each subject, five on each leg in a random sequence.

Subjects

All subject groups were selected to eliminate confounding variables as much as possible. Test groups were evenly divided by gender. Group demographics are shown in Table 1 together with the purpose of each study.

For the study of total knee replacement, the young control group and the age-matched control group were chosen to have no history or symptoms of knee joint disease. The postoperative group consisted of 17 patients who had undergone 19 total knee replacements 32 months before testing on the average. The diagnoses were osteoarthritis in 12, rheumatoid arthritis in 6, and posttraumatic arthritis in 1. The prosthesis type included polycentric (5), total condylar (6), and Noiles (8).

The effect of aging on joint position sense was studied in a group of 29 volunteers ranging in age from 20 to 82 years. All were determined to have normal knees by history and physical examination.

The role of ligament mechanoreceptors in sensing joint position was studied in 10 healthy subjects who had normal knees according to history and physical examination. In this double-blind study, gait parameters and joint position sense were quantified before and after installation of 10 ml fluid into the knee joint. Half received saline and half received 10 ml 2% lidocaine.

The effect of fatigue on joint position sense was studied in 11 healthy male volunteers who were participating in the U.S. Navy Sea, Air, and Land (SEAL) Team training. All volunteers had completed the final and most rigorous phase of training. These subjects were all in excellent physical condition and were chosen as the test group because of their superior muscular conditioning and high level of motivation and thus the ability to achieve a quantifiable degree of muscle fatigue.

Fatigue was induced after a 2-mile warm-up run (average time, 13.2 min) by alternate 1-mile and ¼-mile sprints (90-s rest interval) for a total of 3.75 miles. Two 2-min treadmill sessions at 7 mph with a 15% uphill grade with a 90-s rest between sessions completed the fatigue protocol. Isokinetic testing of work output verified fatigue if at least a 10% decrement from the prefatigue protocol was found subsequent to proprioception measurements.

The effect of athletic training on joint position sense was studied in a group of 12 ballet dancers (5 male, 7 female) from the New Orleans Ballet Company. The individuals in this group had studied and trained in dance for an average of 14 years.

The subject group for the ACL study consisted of 11 patients treated at Naval Hospital, Oakland, with an acute injury to a previously normal knee. All subjects had arthroscopically proven complete mid-substance ACL tears. No patient with a potentially repairable avulsion near the tibial or femoral origin was included. Patients undergoing associated meniscal repair or excision were also excluded. All patients had unequivocal 2+ to 3+ Lachman and pivot shift tests. Patients subsequently were treated with a course of physical therapy that emphasized hamstring strengthening and delayed terminal quadriceps exercises for 6 months. All patients had normal contralateral knees with no history of previous injury, symptoms, or treatment. Six patients were tested with an acute instability (between 3 and 6 months postinjury); the remaining 5 were classified as having a chronic instability (12–60 months postinjury, mean 38 months).

The effect of ACL reconstruction on knee joint position sense was studied in 10 patients (5 males and 5 females, mean age 27 years) treated with autologous patellar tendon grafting. The average time from injury to operation was 10.4 months, and the average time from operation to testing was 31.6

TABLE 1. Subject groups used to study joint position sense

Group	Age (yr)	No. of subjects	Effect studied	Reference
Total knee patients	63.8	17	Arthrosis and arthroplasty	50
Age-matched controls	63.4	11	Arthrosis and arthroplasty	50
Young controls	24.9	11	Arthrosis and arthroplasty	50
Age group	20–82	29	Age	49
Ballet dancers	25	11	Muscle training	5
SEAL trainees	22.8	11	Muscle fatigue	51
Ligament mechanoreceptor study subjects		10	Neutralization of capsular receptors	6
ACL deficient patients	25.2	11	ACL rupture	7
ACL reconstruction patients	27	10	Patellar tendon reconstruction	15

ACL, anterior cruciate ligament.

months. A Stryker knee laxity tester, which evaluates ACL laxity, showed average presurgery anterior tibial displacement of 10.51 ± 1.69 mm (injured knee) and 5.53 ± 1.15 mm (uninjured knee), and postsurgery readings of 6.19 ± 0.76 mm (injured knee) and 6.00 ± 1.12 mm (uninjured knee). The control group consisted of 10 individuals (5 males and 5 females, mean age 24 years) with no history of knee problems. The reproduction test was varied slightly by having the subject passively reproduce the angle with a motor. Isokinetic muscle testing was performed on a Cybex II dynamometer to account for any variations in postoperative muscle function.

Data Analysis

The measurements of joint position sense were analyzed with standard statistical techniques (*t* tested, paired *t* test, analysis of variance, multivariate analysis) with readily available statistical software. A significance level of 5% was used.

RESULTS

The results are summarized in Table 2. No differences in right versus left (or dominant versus non-dominant) measurements were noted for any of the control groups as measured by the paired *t* test.

Aging

A significant difference between young and old control groups was noted in both tests of joint position sense ($p = 0.01$, *t* test). This suggested correlation of the joint position sense with age. When

more subjects were added to broaden the distribution, a significant negative relation between age and position sense was noted, i.e., joint position sense diminished with age. The regression equation for reproduction of joint angle as a function of age ($n = 58$) is reproduction (degrees) = $1.02 + 0.0590 \times$ age (years). The correlation coefficient is 0.570 and is statistically significant ($p < 0.001$). The regression equation for the measurement of threshold to detection of motion as a function of age ($n = 58$) is threshold (degrees) = $3.10 + 0.0456 \times$ age (years). This relation is statistically significant at the $p < 0.001$ level with a correlation coefficient of 0.555. These relations are shown in Figs. 2 and 3.

Total Knee Replacement

Total knee arthroplasty patients demonstrated significantly impaired joint position sense as compared with age-matched controls ($p < 0.005$, *t* test). No significant difference between operated and unoperated knees was noted in either test.

Ligament Mechanoreceptors

The study group showed no difference in joint position sense or in gait parameters during normal walking.

Athletic Training

Ballet dancers were significantly less accurate than controls in their ability to reproduce angles. The test group error in reproducing angles was $4.8^\circ \pm 2.8^\circ$ as compared with $2.6^\circ \pm 1.0^\circ$ ($p < 0.03$). Furthermore, the test group had a significant ten-

TABLE 2. Results of studies of joint position sense

Group	Reproduction degrees (\pm SD)	Kinesthesia degrees (\pm SD)	Reference
Total knee patients	8.4 ± 4.7	8.8 ± 3.2	9,50
Age-matched controls	4.6 ± 2.2	5.9 ± 1.6	9,50
Young controls	2.5 ± 1.0	3.7 ± 1.0	9,50
Ballet dancers	4.8 ± 2.8	2.6 ± 0.8	5
Controls	2.6 ± 1.0	3.9 ± 1.0	5
SEAL trainees, before fatigue	2.90 ± 1.38	1.20 ± 0.79	51
SEAL trainees, after fatigue	3.97 ± 2.50	0.84 ± 0.37	51
ACL deficient patients (injured/uninjured)	—	$3.53 \pm 1.22/2.57 \pm 0.59$	7
Control group (R/L)	—	$2.67 \pm 0.84/2.72 \pm 0.94$	7
ACL reconstruction patients			
Reconstructed	1.76 ± 0.91	1.33 ± 0.76	15
Normal	1.68 ± 0.46	1.20 ± 0.41	15

ACL, anterior cruciate ligament.

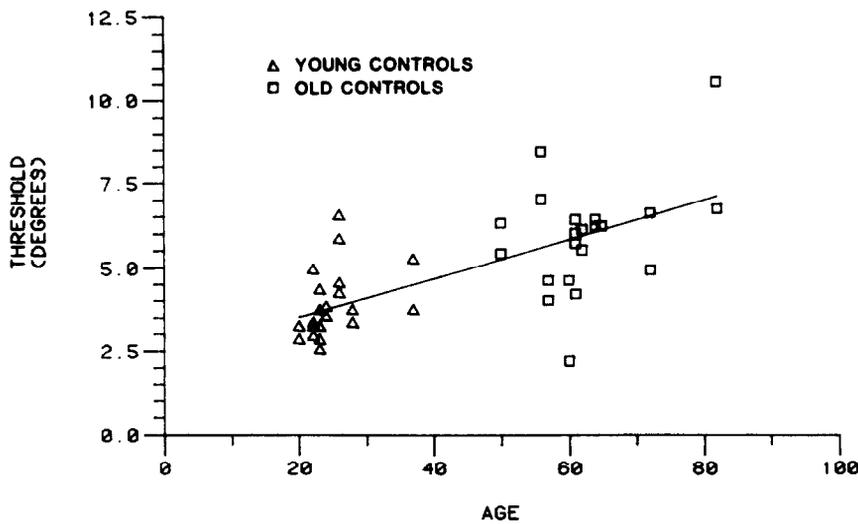


FIG. 2. Angular change in knee position at detection of motion is shown as a function of age.

dency to overshoot ($p < 0.01$, chi-square test). The ability to detect change in position was significantly better than controls ($2.6^\circ \pm 0.8^\circ$ for dancers as compared with $3.9^\circ \pm 1.0^\circ$ for controls, $p < 0.01$).

Fatigue

The fatigue study subjects showed a significant decrease in ability to reproduce angles ($p < 0.05$) and no significant change in threshold of motion detection.

ACL Disruption

The ACL test group showed a significant difference in mean threshold between the injured and noninjured knee ($p < 0.01$). The results in the non-

injured knee were identical to those of controls (Fig. 4). The mean difference between the two knees was 1° , which represented a mean variation $>25\%$ between the two knees. Correlations of right versus left knee and uninjured versus injured knee were significant ($r = 0.942$ and $p = 0.0001$ and $r = 0.642$ and $p = 0.042$, respectively).

Arthrometric measurement of anterior joint laxity in the ACL test group showed an injured-uninjured mean difference of 6.6 mm (range 4–9 mm), which was representative of the moderate to severe degree of joint laxity in the test group. Univariate analysis of variance of the degree of laxity ($n = 11$) showed a significant correlation with threshold measurements ($r = 0.465$, $p = 0.029$). Multivariate analysis performed on 9 of the 11 test subjects for whom

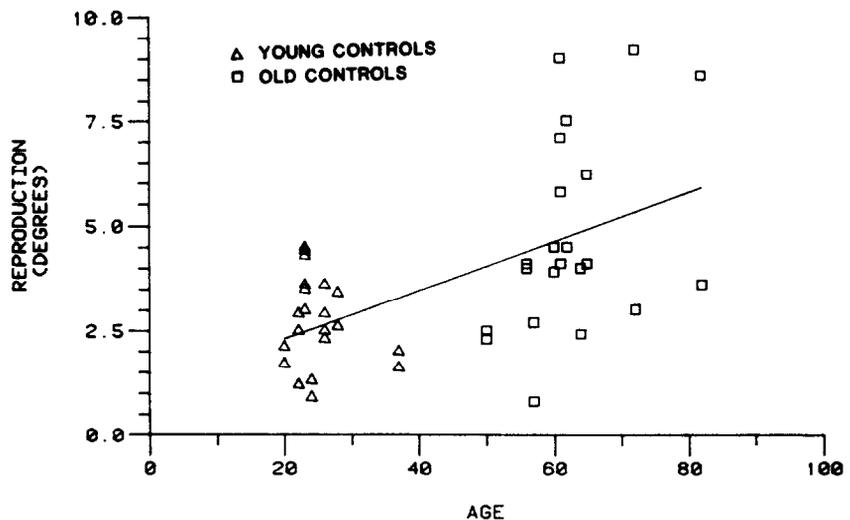


FIG. 3. Ability to reproduce a set angle of the knee is shown as a function of age. The vertical axis is the average difference between set angle and reproduction angle.

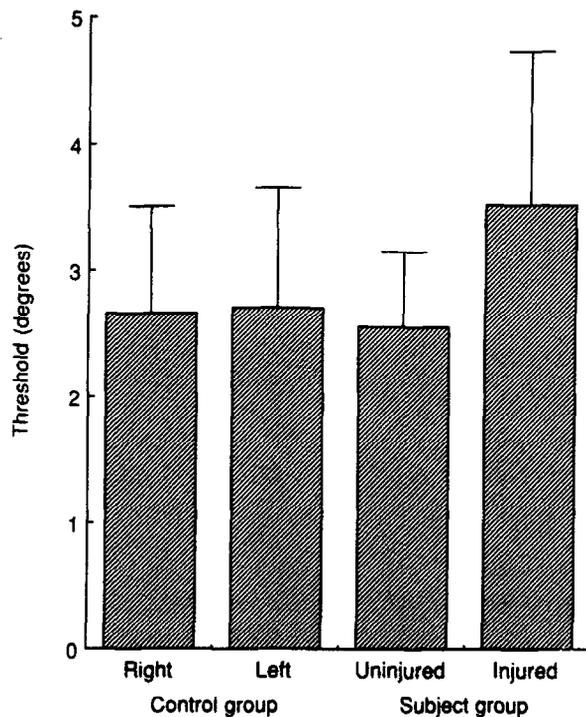


FIG. 4. Threshold to detection of motion results in a normal control group and a group with an injured (anterior cruciate ligament deficient) and an uninjured knee.

complete isokinetic data were available showed that only the absence of an ACL (as a "dummy" variable) and knee arthrometer measurements demonstrated subject-independent significant correlations with measurements of joint position sense. Neither thigh circumference nor any of the isokinetic variables contributed significantly to the increased threshold values in the injured knees of the test group. Furthermore, time since injury and subject age showed no correlation with threshold measurements.

ACL Reconstruction

Joint position sense data for the ACL reconstruction control group was comparable to previous measurements. Ipsilateral and contralateral reproduction data for the study group was not statistically different from the control group, and no differences were shown between the injured and uninjured extremity. Comparison of the threshold measurements for the injured and for the uninjured leg showed no significant difference (paired *t* test), although the uninjured leg was worse [$1.33^\circ \pm 0.76^\circ$ vs. $1.20^\circ \pm 0.41^\circ$ (uninjured)] (Fig. 5). However, the

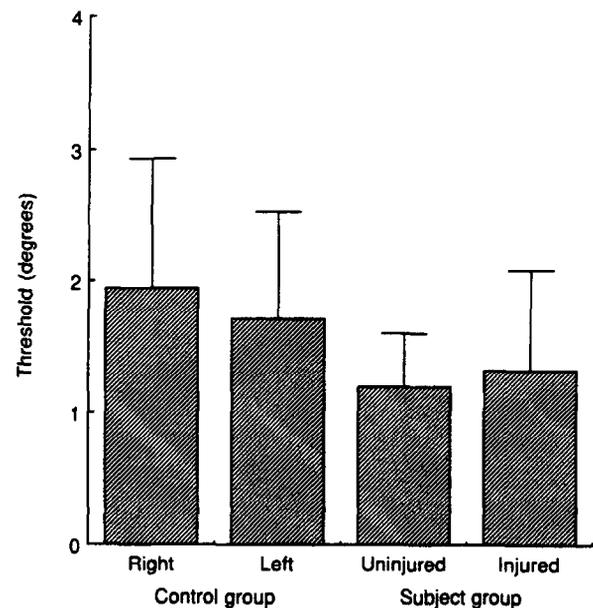


FIG. 5. Threshold to detection of motion results in a normal control group and a group with an injured (anterior cruciate ligament rupture) reconstructed knee and a contralateral uninjured knee.

one-tailed, paired *t* test, which is valid if the null hypothesis is that the kinesthesia in the injured reconstructed knee was equal or worse than the contralateral knee, showed significance at the $p < 0.05$ level. Because this same test in the ACL-deficient study group demonstrated diminished kinesthesia, some credence must be given to this result. Both these measurements were significantly better than the control measurements (injured $p = 0.001$, uninjured $p = 0.001$). In the subject group, multivariate linear regression based on six factors (laxity, heelstrike impulse, gait velocity, age, postoperative time, and presence of ACL injury) correlated ipsilateral reproduction ability to postoperative time ($p = 0.047$) and contralateral reproduction ability to both heelstrike impulse ($p = 0.022$) and velocity ($p = 0.041$).

Degenerative Joint Disease

In the group of patients who had had a total knee replacement, the contralateral knee also had degenerative arthritis to some degree. In fact, most subjects were candidates for future knee replacement. Both knees had kinesthetic deficits of the same degree, and both knees were significantly worse as compared with age-matched controls.

Conclusions

Normal subjects are consistently able to reproduce an angle with their knee with an average error of 2.5°. Normal subjects require 2.5°–4° of movement at a speed of 0.5°/s to detect a change in position. The performance of the fatigue study subjects, the ballet dancers, and the ACL reconstruction group indicates that an improvement in kinesthesia is associated with muscle training. However, the ballet dancers showed a tendency to overshoot and had an impaired ability to reproduce angles as compared with controls. Capsular receptors susceptible to lidocaine diffusion from the joint space do not appear to affect either kinesthesia or reproduction ability in normal subjects. The fatigue group showed a slight increase in reproduction error before exercise as compared with previous controls but significantly worsened after muscular fatigue.

Changes in the knee associated with aging caused moderate deterioration in both measures of joint position sense. Threshold of motion detection in ACL-deficient knees was worse than in control knees but comparable to normal controls from previous studies. The results in the ACL-deficient knees were worse than noted for other study groups but were less severe than those of patients with total knee replacement and/or arthritic changes. A well-performed reconstruction of the ACL appears to offer the opportunity to achieve joint position sense nearly equivalent to the contralateral side but better than controls. Arthroplasty and arthritic patients have the worst joint position sense, but they also have the most joint damage and muscle atrophy.

DISCUSSION AND CLINICAL IMPLICATIONS

The validity of our present data is supported by previous studies of normal subjects. Our normal values for threshold of motion detection (2.5°–4°) agree with the range of 2°–4° measured by Horch et al. (14) and Clark et al. (28); both groups used a similar technique at about the same speed. Slight variations between study groups are explained by slight variations in speed or flexion angle of measurement. Kinesthetic response is known to depend on the angle and speed at which measurements are taken (33,52). Different receptor populations are specific for each range of flexion (25). Subsequent to initiation of these studies, Kaplan et al. (37) used

a reproduction test to study young and old women. They confirmed our results on aging, showing that young women reproduced angles with a mean error of 4° whereas older women (>60 years) had a mean error of 7°. Their results in young women coincided closely with our 2.5° mean reproduction error.

Further results on total knee replacement patients by Faris et al. (19) showed average threshold and reproduction values of ~5.5° and 12.1°–13.8°, respectively, in fair agreement with our result of 8.8° and 8.4°, respectively. Candidates for TKA have abnormal laxity of the ACL as well as other knee ligaments. Occasionally, such a patient will have a normally functioning ACL, but it is usually excised in the process of performing the knee replacement. Lack of input from the ACL and other compromised knee ligaments may contribute to the kinesthetic deficit observed in patients who have undergone TKA.

Harter et al. (26) measured ipsilateral reproduction of position of the knee in patients with ACL reconstructions and noted no differences from the normal knee at time periods >3 years. In a similar study at an average of 15 months postreconstruction, Newberg (44) reported a significant decrease as compared with the normal knee at 30° of flexion and no difference at 70°.

In general, introduction of variables such as aging or ACL disruption tended to produce an increase in the variability of the results of joint position sense measurements. This may be an indication of the variability in anatomy or anatomic damage associated with those conditions. Certain individuals may rely to a greater extent on or receive a greater proportion of afferent input from their ACL and other associated capsular structures. Kennedy et al. (38,39) showed significant variability in the pattern of innervation of ligaments in humans, including the ACL, and subsequent investigators showed differences in the number of mechanoreceptors among different knees examined (47,48). Schultz et al. (47) noted only one intact receptor in total knee ACL specimens, owing to the destruction of the arthritic process. The lack of receptors in arthritic ligaments and the presence of receptors in autopsy and amputation specimens reported by Schultz et al. (47) support our findings of decrease in joint position sense with arthritis and total knee replacement. In addition, anatomic variability in receptors, degree of ligamentous laxity, and muscle tone may permit variable compensation from input through muscle or tendon receptors.

The observed deterioration in joint position sense with age, arthritic change, total knee replacement, and ligamentous injury raises clinical questions. Muscle atrophy concomitant with the decreased activity levels associated with aging or knee surgery may contribute to diminished joint position sense. Diminished joint position and pain sense are crucial in the development of Charcot or neuropathic joints (27). Johnson (35) suggested that abnormal joint position sense played a role in causing Charcot joint formation. Finsterbush and Friedman (20) have shown that sensory denervation of joints without motor loss results in degeneration of chondrocytes in the cartilage of joints. Thus, normal knees, aging knees, arthritic knees, and Charcot knees may be points on a spectrum of joint position sense. The studies discussed show that between the ages of 25 and 60 years kinesthesia and the ability to reproduce an angle diminish by an average of 38 and 83%, respectively (49). Degenerative joint disease and aging have been shown in these studies to be associated with diminished joint position sense and thus may be the result of subclinical defects in joint position sense. On the other hand, our findings of degenerative arthritis in the contralateral knees of TKA patients and of kinesthetic deficits comparable to those in the operated knees suggest that this deficit is secondary to the arthritic process. Furthermore, this deficit is not improved or worsened by knee replacement.

The ACL-deficient knee as a clinical and experimental entity has been demonstrated to result in osteoarthritis (10,32,36,41). Degenerative changes have been attributed to mechanical effects (23,41), but these mechanical effects may be accentuated by a lack of kinesthetic input that permits microdamage to occur due to inappropriate damping of loads. Furthermore, clinical experience suggests that the ACL-deficient knee is predisposed to meniscal tears. Significantly, knees with untreated meniscal tears and with removed menisci are known to result in degenerative changes of the joint (29,42,43). Inadequate joint position sensory input may be a contributing factor in the etiology of these meniscal lesions and subsequent degenerative joint disease.

Muscular training may offer a means of counterbalancing the effects of diminished joint position sense resulting from injury, aging, or arthritic change. Our results suggest that the normal knee demonstrates better kinesthetic function after muscle training because of the role played by muscle receptors in trained athletes who underwent fatigue

and in ballet dancers. Furthermore, the results of ACL reconstruction patients indicate that intensive postoperative muscle training can restore joint position sense to normal or better. Patients who undergo reconstruction may be a subgroup of individuals with ACL ruptures who either have had an ACL mechanoreceptor deficiency or who have been more motivated to overcome muscle atrophy. Thus, our results support the rehabilitation efforts made by knee surgeons on ACL reconstruction patients and TKA patients with the caveat that anatomic variation may produce variable results.

Agility training has been advocated as a portion of the rehabilitation of ACL reconstruction patients (17). In a recent study of isometric muscle training and training to achieve "dynamic joint control," Ihara and Nakayama (30) reported that although peak torque time for the hamstrings was improved, there was no correlation between this measure of reaction time and isometric strength. Thus, simple isometric strength training apparently does not produce the beneficial effects of dynamic balance training with tools such as unstable platforms. Walla et al. (54) reported that in 95% of patients who were able to compensate successfully for an ACL injury without operation, active hamstring control reduced the pivot shift. Furthermore, a simple reproduction test and/or kinesthesia test may be important in evaluating postoperative competitive ACL patients as an endpoint in determining readiness for full activity and as a means of determining prognosis.

CONCLUSION

Mechanoreceptors are specialized nerve endings that enable awareness of joint position in space and initiate stabilizing and protective reflexes. These receptors have now been well demonstrated in human knee ligaments—specifically, the cruciates. Objective measurement of position sense has shown that kinesthesia decreases as a part of normal aging. In degenerative joint disease this function decreases more markedly and may even prove to be a contributing etiologic factor. This at least partially explains the abnormal gait pattern of persons with arthritis and why gait does not return to normal after joint replacement even though pain is relieved and deformity is corrected. Muscular training may have a role in reversing this pattern at least partially. Finally, decrease in position sense occurs in at least some patients after ligament injury. Because these

same receptors initiate stabilizing reflexes, tear of the ACL and associated capsular structures may cause a loss of sensory input that contributes to the progressive laxity and disability that commonly occurs over time.

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